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INVESTIGATING CLOSED-LOOP CONSTRUCTION AS A SUSTAINABLE STRATEGY FOR REDUCING AIR POLLUTION IN JOS SOUTH LOCAL GOVERNMENT AREA, PLATEAU STATE

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ABSTRACT

The construction industry remains one of the largest contributors to air pollution through emissions from heavy machinery, material production, transportation, and waste generation. Despite increasing advocacy for sustainable construction, the sector continues to operate largely under a linear take–make–dispose model that intensifies environmental degradation and resource depletion. This study investigates closed-loop construction as a sustainable strategy for reducing air pollution, drawing upon the Circular Economy, Industrial Ecology, and Sustainability theories. A descriptive survey design was employed, involving 127 professionals including architects, engineers, contractors, and environmental officers selected purposively from the construction industries in Jos South Local Government Area. Data were collected through a structured questionnaire and analysed using descriptive statistics and the Relative Importance Index (RII)**.** Findings revealed that emissions from construction machinery and vehicles are the most significant source of air pollution (RII = 0.46), followed by material transport and the use of hazardous chemicals. Linear construction practices were found to exacerbate pollution primarily through material production (RII = 0.46) and waste generation (RII = 0.42). In contrast, closed-loop construction demonstrated strong potential to reduce air pollutants by enhancing material efficiency (RII = 0.45), minimising waste (RII = 0.43), and reducing transportation emissions (RII = 0.42). The study concludes that integrating closed-loop strategies—such as recycling, reuse, and life-cycle design can significantly mitigate air pollution while improving environmental and economic performance. It recommends that governments and construction firms institutionalise circular construction principles, adopt cleaner technologies, and employ life-cycle assessment tools to guide sustainable project planning and emission management.

Keywords: Closed-Loop, Construction, Strategy, Air, Pollution, Reduction

Introduction

Air pollution is a critical environmental challenge that affects millions of people worldwide (Islam, 2025). It is also important to understand that the construction industry generally is a significant contributor to air pollution primarily through emissions from machinery, transportation, and the production of construction materials (Bărbulescu & Hosen, 2025). Casketing to the local construction environment, construction activities and operations lead to elevated concentrations of air pollutants, including particulate matter and volatile organic compounds (Souza et al., 2025). It is important to consider closed-loop construction towards mitigating the challenges of air pollution in our societies. A closed-loop system of construction and demolition waste recycling traditionally use construction materials characterised by a linear process of extraction, manufacture, construction, maintenance and refurbishment, demolition, and disposal (Brennana, 2014). Construction activities have a significant impact on air pollution, with the sector contributing 23 percent of air pollution globally (Okure, 2025). The use of diesel engines, demolition, burning, and toxic materials are major sources of air pollution in construction. As a result, there is an urgent need to adopt sustainable practices and reduce the environmental impact of construction projects. Construction activities have a significant impact on air quality, contributing to various harmful pollutants. Construction sites, whether in urban or rural areas, generate emissions that can go unnoticed compared to more visible sources like traffic (Zezhou, 2025). Construction works release particulate matter, volatile organic compounds, nitrogen oxides, carbon monoxide, carbon dioxide, and other toxic gases. Diesel engines powering construction vehicles and machinery are major sources of these air pollutants, along with dust from demolition and earthworks activities (Wells, 2025). Closed-loop construction refers to a sustainable approach that aims to minimize waste and maximise resource efficiency by reusing and recycling materials within the construction process (Kumar & Singh, 2021). This model aims to create a sustainable building environment by ensuring that materials used in construction are reused, recycled, or repurposed at the end of their life cycle. Closed-loop construction contrasts with traditional linear construction practices, which often result in significant waste generation and environmental degradation. Closed-loop construction reduces the demand for new materials and also lowers emissions associated with material production and transportation (Almusaed et al., 2024).

Statement of the Problem

The construction industry remains a major contributor to air pollution through generation of dust, particulate matter, heavy equipment emissions, and production of construction materials with high embodied energy. According to recent studies, the construction sector accounts for significant gaseous and particulate emissions that negatively impact human health and urban air quality (Shahnavaz & Akhavian, 2021). Concurrently, the industry is still dominated by a linear "take-make-dispose" model of resource use, generating large volumes of waste and requiring fresh raw material extraction practices that exacerbate climate change and air-quality degradation (Fagone, Santamicone, & Villa, 2023; RPRA, 2025). Although the concept of circular or closed-loop construction is increasingly advocated as a sustainable alternative one which emphasises reuse, recycling, and the retention of materials in productive use (Geissdoerfer et al., 2017; Fagone et al., 2023) its potential to mitigate air pollution specifically has not been empirically investigated to a sufficient degree. The knowledge gap lies in understanding how, to what extent, and under what conditions closed-loop construction practices can reduce air pollutants during construction and throughout the building lifecycle. Without such insights, policymakers, industry practitioners, and regulators lack a clear evidence-based pathway to integrate closed-loop strategies into air-quality improvement frameworks in the construction sector.

Thus, this research aims to investigate closed-loop construction as a sustainable strategy for reducing air pollution by identifying key mechanisms, quantifying emission-reduction potentials, and exploring implementation barriers and enablers within the construction industry.

Objectives of the Study

The aim of the study is to investigate closed-loop construction as a sustainable strategy for reducing air pollution**.** The aim was pursued through the following objectives:

1. to assess characteristics and sources of air pollution in the construction
2. to identify principles, consequences, and impact of linear construction on air pollution, and
3. to determined merit and impact of closed-loop construction on air pollution.

Literature Review

The impact of construction pollution extends beyond the environment, as it can cause respiratory issues, eye irritation, sleep disturbances, and increased risk of cardiovascular diseases, especially in vulnerable populations (Jain, 2024). Closed loop construction nibs in the bud the pollution concerns that has been (Adetuyi et al., 2024). In the last two decades there has been glamour for a shift in the construction industry from linear production and consumption of materials and products to some cyclic manufacturing activities (Martins et al., 2025). The agitation is for products and components used in construction to be designed in such a way to enable materials to maintain their status as resources (Kallayil et al., 2025). As such at their end-of-life cycle, materials are re-entered further into another life cycle in substitution of virgin materials (Brennana et al., 2014). As urbanisation continues to rise, the need for sustainable construction practices becomes increasingly urgent. Closed-loop construction, which emphasises the reuse and recycling of materials, presents a promising solution to reduce air pollution associated with construction activities. This paper aims to analyse the potential of closed-loop construction as a game-changing strategy for air pollution reduction.

Air pollution is primarily caused by the release of harmful substances into the atmosphere, including particulate matter (PM), nitrogen oxides (NOx), sulfur dioxide (SO2), and volatile organic compounds (VOC) (Kallayil et al., 2025). The construction industry contributes to these emissions through various processes, including the extraction of raw materials, transportation, and on-site activities (Zhang et al., 2020). Challenges of a healthy built environment include air pollution in construction industry Particulate matter (PM) is one of the most common air pollutants globally together with nitrogen oxides (NOx), photochemical oxidants incl. ozone (O_3), carbon monoxide (CO), lead (Pb), and sulfur dioxides (SO_2) (Alao, 2025). Numerous people suffer from diseases such as acute respiratory diseases, chronic obstructive pulmonary disease, lung cancer, heart disease, and strokes due to air pollution (Antonija, 2021). Others even die due to household and ambient air pollution and its consequences; the number of these fatalities was around 7 million in 2016. Antonija et al (2021) continued that "All regions worldwide are affected by air pollution, and the air pollution limits set by the World Health Organisation (WHO) are met for only 9% of the world's people. Most at risk are people living in low- and middle-income countries, where 94% of all pollution-related deaths occur. According to the European Environmental Bureau, air pollution is also the reason for over 400,000 premature deaths in the European Union (EU).

Construction sites are responsible for 14.5 percent of particulate matter in the air and 8 percent of total emissions in the United States. The Environmental Protection Agency of the United States of America has updated and strengthened air quality standards to better protect communities from harmful particulate matter (PM) like soot and pollution (Yarlagadda, 2022). Dust nuisance, the circulation of machinery, demolition operations, or the loading and unloading of materials, contribute to deteriorating air quality. All of these are linear construction methods that is hinged on take, use and dispose instead of the closed loop construction that ensures every single material is used throughout the material life cycle thereby protecting the virgin materials from being exploited and processed (Ibe et al., 2025).

Machinery onsite releases noise, dust, and gases like NOx and CO, while transport and handling of materials further elevate particulate pollution levels. It's reported that construction accounts for 14. 5% of PM2. 5 and 8% of PM10 emissions, with hazardous substances like paints and glues adding to air quality issues (Jiao, et al., 2025). Consequently, construction is a leading pollution source, responsible for 4% of particulate emissions and more water pollution incidents than any other industry, underscoring the need for effective pollution reduction strategies (Kallayil et al., 2025). Construction activities contribute to air pollution through various means, including the use of diesel-powered machinery and vehicles, the movement and handling of construction materials, demolition work, and the release of harmful chemicals. The burning of fossil fuels and the use of hazardous substances like paints, glues, and plastics also play a role in emitting pollutants into the atmosphere (Ibe et al., 2025). Additionally, construction projects can disturb and expose existing subsurface pollution, leading to further contamination (Alao, 2025). The scale and duration of construction activities significantly impact the level of air pollution generated, with large-scale and long-term projects having more significant effects on the environment and surrounding communities (Jiao, et al., 2025).

Theoretical Framework

This study is anchored on three interrelated theoretical foundations: the Circular Economy Theory, the Industrial Ecology Theory, and the Sustainability Theory. Together, these frameworks provide a holistic understanding of how closed-loop construction can contribute to air pollution reduction and environmental sustainability in the built environment. The Circular Economy (CE) theory proposes a shift from the traditional linear "take–make–dispose" production model to one based on resource efficiency, regeneration, and waste minimization. According to Geissdoerfer, Savaget, Bocken, and Hultink (2017), the CE model emphasises closed material loops where products and materials are reused, refurbished, and recycled to extend their lifecycle and minimise environmental externalities. In the context of construction, this theory supports closed-loop practices such as material recovery, design for disassembly, and adaptive reuse, which collectively reduce the need for raw material extraction and lower emissions from material production and transportation (Pomponi & Moncaster, 2017).

The Industrial Ecology (IE) theory views industrial systems as part of a broader ecosystem, emphasising the optimization of resource flows and energy efficiency to achieve environmental balance (Graedel & Allenby, 2010). It advocates for industrial symbiosis, where waste or by-products from one process become inputs for another, reducing overall emissions and environmental degradation. Applied to construction, IE offers a systemic approach to understanding how material and energy exchanges within the construction supply chain can minimise pollution and resource depletion (Chertow, 2000). This theory strengthens the argument that closed-loop construction can create inter-industry linkages that reduce air pollutants and promote sustainability. The Sustainability Theory underpins the long-term balance between environmental protection, economic viability, and social well-being (WCED, 1987). It posits that development should meet the needs of the present without compromising the ability of future generations to meet their own needs. Within this study, the sustainability framework justifies closed-loop construction as a viable strategy for reducing air pollution while enhancing resource efficiency and social equity in urban environments (Dempsey, Bramley, Power, & Brown, 2011). The integration of sustainability principles ensures that closed-loop construction practices are not only environmentally sound but also economically and socially beneficial.

Methodology

This study adopted a descriptive survey research design to investigate closed-loop construction as a sustainable strategy for reducing air pollution. The population of the study comprised 187 respondents, including architects, engineers, contractors, and environmental officers involved in construction projects Jos South Local Government Area. From this population, a sample of 127 respondents was selected using a purposive sampling technique to ensure inclusion of participants with relevant expertise in sustainable construction practices. Data were collected using a structured questionnaire designed on a 5-point Likert scale ranging from “strongly disagree” to “strongly agree,” as recommended for measuring attitudes and perceptions in social research (Likert, 1932). The instrument’s reliability was established through a pilot test, yielding a Cronbach’s alpha coefficient of 0.87, indicating a high level of internal consistency (Tavakol & Dennick, 2011). Validity of the instrument was ensured through expert review by professionals in construction management and environmental science, in line with guidelines for content validation in survey research (Creswell & Creswell, 2018). The data collection was conducted face-to-face to enhance accuracy and completeness of responses. Collected data were analysed using descriptive statistics, including mean, while the Relative Importance Index (RII) was employed to rank the characteristics and sources of air pollution in the construction, principles, consequences, and impact of linear construction on air pollution, and merit and impact of closed-loop construction on air pollution, following the method outlined by Kometa, Olomolaiye, and Harris (1994).

Results

Table 1: Respondents' Background Information

Summary of Information	Frequency	Percentage (%)	Cumulative Percentage
Role of Respondents in their Organisation			
Construction Manager	13	10.24	10.24
Project Supervisor	10	7.87	18.11
Site Engineer	11	8.66	26.77
Head of Valuation	10	7.87	34.64
Building/Estate Officer	13	10.24	44.88
Director/Property Manager	12	9.45	54.33
Principal Partner/ Chief Executive Officer	11	8.66	62.99
Surveying Geo-Informatics	12	9.45	72.44
Project QS	11	8.66	81.10
Procurement Officer	12	9.45	90.55
Academics	12	9.45	100.00
Total	127	100.00	
Professional Field			
Architecture	26	20.47	20.47
Building	26	20.47	40.94
Engineering (Civil, Structural, Mechanical, Electrical)	26	20.47	61.41
Quantity Surveying	21	16.54	77.95
Estate Management and Valuation	22	17.32	95.27
Others	6	4.73	100.00
Total	127	100.00	
Highest Academic Qualification			
Diploma	11	8.66	8.66
Higher National Diploma	25	19.69	28.35
BSc/BEgr	67	52.75	81.10
MSc/MBA	20	15.75	96.86
PhD	4	3.15	100.00
Total	127	100.00	

The results of the study present respondents' demographic characteristics alongside findings on the sources and impacts of air pollution, the effects of linear construction practices, and the merits of closed-loop construction as a sustainable alternative. The demographic analysis indicates that respondents occupy diverse professional and academic positions across the construction industry, including senior management, technical experts, and academics. Approximately 18% of the participants held top-level roles (Directors and Chief Executive Officers), while 19% possessed postgraduate qualifications (MSc/MBA/PhD). The professional distribution shows a balanced representation across Architecture, Building, and Engineering (each 20%), Quantity Surveying (17%), and Estate Management (17%). Overall, more than 70% of respondents held at least a bachelor's degree, suggesting a technically competent and experienced sample drawn from multiple disciplines within the built environment sector (see Table 1).

Table 2: Characteristics & Sources of Air Pollution

S/N	Characteristics & Sources of Air Pollution	5th	4th	3rd	2nd	1st	Total	RII Value	Rank
1	Construction Machinery and vehicles: Diesel fuel is used to power construction machinery and vehicles, which releases pollutants such as carbon-dioxide, nitrogen oxides, and hydrocarbons	50	10	1	0	0	293	0.46	1st
2	Movement of machinery and transport of construction materials: The movement of machinery and the transport of construction materials can contribute to higher pollution, especially in the case of particulate matter	45	6	5	2	3	271	0.43	2nd
3	Use of hazardous chemicals: Emissions from hazardous chemicals like paints, glues, oils, thinners, plastics, and cement can contribute to air pollution	43	5	6	4	3	264	0.42	3rd
4	Burning of fossil fuels: The construction process requires the burning of fossil fuels, which produces greenhouse gases	36	8	7	8	2	251	0.40	4th
5	Volatile organic compounds (VOCs): VOCs are emitted gases that are harmful on their own and can react with other gases in the air to form dangerous pollutants. Common VOCs include benzene, formaldehyde, and trichloroethylene	35	9	10	1	6	249	0.39	5th
6	Particulate matter: Particulate matter is one of the most harmful emissions from construction sites due to its microscopic size. These particles can contribute significantly to air pollution and can contain sulfates and silicates.	35	6	5	7	8	236	0.37	6th
7	Energy Use: Newly manufactured and constructed buildings use energy, which can add to air pollution.	35	5	6	6	9	234	0.36	7th

The analysis of the characteristics and sources of air pollution reveals that emissions from construction machinery and vehicles were identified as the most significant contributor (RII = 0.46), followed by movement of machinery and transport (RII = 0.43) and use of hazardous chemicals (RII = 0.42). In contrast, energy use in new buildings recorded the lowest perceived impact (RII = 0.36). These findings, as summarized in Table 2, highlight the primary operational activities within construction that contribute most to air pollution, providing a data-based ranking for prioritising mitigation strategies.

Table 3: Principles Consequences, & Impact of Linear Construction on Air Pollution

S/N	Principles Consequences, & Impact of Linear Construction on Air Pollution	5th	4th	3rd	2nd	1st	Total	RII Value	Rank
1	Material Production: Reduces material efficiency, requires energy for new production of materials; High emissions associated to material extraction and processing	49	9	1	1	1	289	0.46	1st
2	Waste Maximization: High volume of waste generated and discarded or burnt-out; Emission of air pollutants like dust, CO_2	45	6	2	2	6	265	0.42	2nd
3	Transportation: Moving of waste materials to landfills or waste sites and transportation of new materials from factories to markets and sites; High burning of fossil fuel at the course of transportation	42	5	6	4	4	260	0.41	3rd

The analysis of the principles, consequences, and impacts of linear construction on air pollution was conducted using respondents' perceptions of the severity of environmental effects associated with typical construction and manufacturing processes. Three major impact categories material production, waste maximization, and transportation were identified and ranked accordingly. As shown in Table 3, material production recorded the highest Relative Importance Index (RII = 0.46), indicating that the greatest environmental burden occurs at the initial stage of the construction life cycle. Waste maximization ranked second (RII = 0.42), reflecting perceptions of high inefficiency and pollution associated with current linear practices, particularly through waste burning and disposal. Transportation ranked third (RII = 0.41), suggesting that emissions from logistics activities, including the movement of raw materials and waste, significantly contribute to air pollution. Overall, these findings establish a clear hierarchy of environmental impacts within linear construction, identifying material production and waste generation as critical areas for targeted intervention and policy action.

Table 4: Merit and Impact of Closed-Loop Construction on Air Pollution

S/N	Merit & Impact of closed-loop construction on air pollution	5th	4th	3rd	2nd	1st	Total	RII Value	Rank
1	Material Efficiency: Promotes the reuse and recycling of materials, which reduces the need for new material production; Lowers emissions associated with material extraction and processing,	48	9	1	1	2	283	0.45	1st
2	Waste Minimisation: Reduces the volume of waste transported to landfills, which is often a source of air pollution due to dust and emissions from waste management processes; Lower emissions associated with waste management	46	5	3	4	6	273	0.43	2nd
3	Reduced Transportation: Less transportation of old and new materials required; Reduced emissions from fossil fuel due to low transportation	47	4	4	2	4	271	0.42	3rd

The analysis of the merits and impacts of closed-loop construction on air pollution identified three key benefit categories material efficiency, waste minimisation, and reduced transportation ranked according to their Relative Importance Index (RII) values. As shown in Table 4, material efficiency ranked highest (RII = 0.45), indicating that stakeholders perceive the most substantial environmental and economic benefits to arise from interventions at the design and material selection stages. Waste minimization ranked second (RII = 0.43), emphasizing the importance of reducing the volume of waste transported to landfills, which often contribute to air pollution through dust and emissions from waste processing. Reduced transportation ranked third (RII = 0.42), reflecting recognition of the indirect yet significant benefits of circular practices in lowering emissions associated with logistics and material movement. Collectively, these results suggest that prioritising material efficiency and localized reuse strategies within closed-loop construction systems can effectively mitigate air pollution while enhancing overall sustainability performance.

Discussion of Findings

The results indicate that emissions from construction machinery and vehicles represent the most significant source of air pollution, primarily due to the combustion of diesel fuel, which releases carbon dioxide (CO_2), nitrogen oxides (NO_x), and hydrocarbons. This finding aligns with the Industrial Ecology Theory, which emphasises the optimisation of material and energy flows across production systems. It suggests that improving machinery efficiency and transitioning toward cleaner energy technologies could substantially reduce emissions at the source. Movement and transport of materials ranked second, highlighting that logistics processes contribute meaningfully to fugitive dust and exhaust emissions. This underscores the need for systemic approaches—consistent with Sustainability Theory that minimise environmental externalities throughout supply and transport networks. The ranking of hazardous chemical use further emphasizes the role of material selection and process management in determining air quality outcomes. These results reinforce the Circular Economy Theory**,** which advocates for substituting harmful materials with low-emission, recyclable alternatives and improving on-site handling to maintain closed material loops. The prominence of particulate matter (PM) and volatile organic compounds (VOC) among identified pollutants illustrates the intersection between environmental degradation and occupational health. Such pollutants are well-established contributors to respiratory and cardiovascular disorders (Wang et al., 2019), thereby connecting sustainability objectives directly with human well-being. By interpreting these findings through the theoretical lens of circularity and systemic efficiency, the study highlights that reducing emissions from machinery, materials transport, and chemical use requires interventions designed at the system level, not merely at isolated operational points.

Furthermore, the observed alignment between the principles and consequences of linear construction and the product life-cycle stages production, use, and disposal demonstrates the need for an integrated Life-Cycle Assessment (LCA) framework when evaluating environmental impacts. This perspective is consistent with Bărbulescu and Hosen (2025)**,** who argued that LCA provides a comprehensive means to capture the cumulative environmental burden across all phases of material use. Collectively, these findings provide empirical support for theoretical propositions that closed-loop construction enhances resource efficiency, mitigates emissions, and advances the transition from a linear to a circular construction economy (Lee et al., 2022; Kallayil et al., 2025).

Conclusion

This study investigated closed-loop construction as a sustainable strategy for reducing air pollution, drawing on Circular Economy, Industrial Ecology, and Sustainability theories to interpret the findings. The results revealed that emissions from construction machinery and vehicles, material transport, and the use of hazardous chemicals constitute the primary sources of air pollution in the construction sector. In contrast, closed-loop practices particularly those emphasising material efficiency, waste minimisation, and reduced transportation were shown to offer measurable environmental benefits. These findings directly address the study's objectives by identifying key emission sources, evaluating sustainable mitigation mechanisms, and linking theoretical principles to practical interventions. The evidence supports the view that applying closed-loop strategies throughout the construction life cycle can substantially reduce air pollutants, enhance resource efficiency, and align construction practices with broader sustainability goals. Consequently, the study reinforces the theoretical proposition that systemic material circularity and integrated life-cycle thinking are essential for achieving long-term environmental sustainability in the built environment.

Recommendations

In line with the findings, it was recommended that:

1. Construction firms should prioritise the reduction of emissions from machinery and vehicles by transitioning to electric or hybrid equipment and enforcing regular emissions testing in line with sustainable engineering standards by governement.

2. Project planning and procurement processes should incorporate Life-Cycle Assessment (LCA) tools to evaluate and manage emissions across all stages of construction by both government and private organisations.
3. Mainstreaming closed-loop construction principles should be incorporated within national and institutional sustainability frameworks for both government and private organisations.

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